Claims

1. A new method for determining in-situ bulk tortuosity of the interconnected pores of the reservoir rock, and estimating the bulk permeability of a reservoir formation connected between two wells, by analyzing the seismic signal transmitted into said formation from within one wellbore and received in another wellbore, said seismic signals including selected discrete frequencies. The method comprising:

   Spectrally analyzing said received signals, determining the presence of the Drag-Wave by determining the presence of the frequency side lobes of the Primary seismic wave, of a selected discrete frequency, the frequency side lobes in the said spectrum of the received signals being created by the nonlinear elastic interaction of the Primary mono-frequency seismic wave with the Drag-Wave, the Drag-Wave being generated through solid/liquid coupling as the Primary Compressional Wave propagates through a permeable reservoir formation between two wells, and the said formation has fluid-filled interconnected pores.

2. The method in Claim 1 further comprising:

   Determining the frequency of the side lobes in the frequency spectrum of the received signals, created by summing and differencing of the Primary signal frequency and the Drag-Wave frequency, caused due to elastic nonlinear interaction as the two waves propagate simultaneously through a permeable and elastically nonlinear rock.

3. The method in Claim 1 further comprising:

   Using the determined side lobe frequencies, to calculate the Drag-Wave frequency, since the frequency side lobes are the result of the summing and differencing of the Drag-Wave frequency and the Primary input frequency.

4. The method in Claim 1 further comprising:

   Determining the Compressional Wave velocity of the rock formation between the two said wells using the seismic first arrival times of the received and recorded signal transmitted from the seismic source in one well and received in the second well, by knowing the distance between the wells and the time of arrival, the velocity can be calculated.

5. The method in Claim 1 further comprising:

Using the value of the Primary wave input frequency and the calculated Drag-Wave frequency along with the calculated Compressional Wave velocity of the rock formation between the two said wells, the Drag-Wave velocity in the said formation between the two said wells can be calculated.

6. The method in Claim 1 further comprising:

Determine the bulk tortuosity of the in-situ reservoir formation between the said two source and receiver wells, based on the calculated Drag-Wave velocity and the compressional velocity of the pore fluids derived from the well logs and the fluid samples from the said wells.

7. The method in Claim 1 further comprising:

Estimate the bulk permeability of the in-situ reservoir rock formation connected between the two said wells, based on the calculated value of the tortuosity and the values of porosity and average pore radius derived from the well logs and the core samples of the reservoir rock.

8. The method in Claim 1 further comprising:

Determining the relative amplitude of the Primary input frequency side lobes in relation to the amplitude of the Primary frequency as received and recorded in the said receiver well, using this relative amplitude value as a qualitative measure of the in-situ rock properties of the reservoir formation between one well pair to the next well pair in a field.

9. A method for determining in-situ bulk tortuosity of the interconnected pores of the reservoir rock, and estimating the bulk permeability of the reservoir formation in a well between two depth points in that well, by analyzing the seismic signal transmitted into the said formation from a source at known depth and receiving and recording that signal at another predetermined and known depth, said seismic signals including selected discrete frequencies.

The method in Claim 9 comprising:

Spectrally analyzing said received signals, determining the presence of the Drag-Wave by determining the presence of the frequency side lobes of the Primary seismic signal transmitted, determining the frequency and the velocity of the Drag-Wave, from that calculating the tortuosity of the rock

formation and use that value of tortuosity to estimate the rock bulk permeability.